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AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM (ASTROS) DAMAGE TOLERANCE MODULE

VOLUME II -- USER'S MANUAL

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FINAL REPORT FOR 09/30/1996 – 09/30/1998

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This report was developed under SBIR contract.
This report is part of the documentation that describes the complete development of an SBIR Phase II effort titled, "An ASTROS Compatible Computational Strategy for Evaluating the Aeroelastic Response, Buckling, and Integrity of Composite A/C". This report is one of three manuals that comprise the final documentation. The remaining reports consist of a Final Report, Volume I, and an Interface Design Document, Volume III.

The Automated STRuctural Optimization System (ASTROS) is a multidisciplinary computer program for the preliminary design of aircraft and spacecraft structures. It integrates structures, aerodynamics, controls and optimization to make possible interdisciplinary design.

This report describes the user input necessary to exercise the damage tolerance module. In addition to standard ASTROS input data cards for the description of the preliminary design model, the user has to specify the following information to analyze discrete source damage: the master element, the layout and properties of the panel, the damage, and the analysis control parameters using bulk data cards. A detailed description of the bulk data cards introduced by the damage tolerance module is discussed and a brief summary with examples is also given.

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FOREWORD

This is the final report on the work performed by Knowledge Systems, Inc. on the U.S. Air Force Contract F33615-96-C-3215, "An ASTROS Compatible Strategy for Evaluating the Aeroelastic Response, Buckling and Integrity of Composite A/C". This report contains 3 parts: 1) "ASTROS Damage Tolerance Module: Final Report"; 2) "ASTROS Damage Tolerance Module: Interface Design Document"; and 3) "ASTROS Damage Tolerance Module: User's Manual".

This report details the work performed to enhance the capability of ASTROS to perform preliminary design optimization of metallic and composite material aircraft, based on damage tolerance requirements. The customized damage tolerance models that have been implemented in ASTROS, at present, are:

1. Discrete Source Damage Model: A lead crack in a stiffened panel with/without the presence of a central broken stiffener;
2. BuckDel model: Buckling of a composite panel in the presence of a delamination;
3. Straight Crack Model: A panel with a central crack;
4. Rivet Hole Crack Model: One (or two) crack(s) emanating from one side (or both sides) of a rivet hole;
5. Curved Crack Model: A panel with a curved crack;
6. Rivet Hole Curved Crack Model: One (or two) curved crack(s) emanating from one side (or both sides) of a rivet hole;
7. Surface Crack Model: One centered surface crack in a plate;
8. Rivet Hole Corner Crack Model: Two corner cracks emanating from both the sides of a straight-shank rivet hole.

The authors acknowledge the contributions of D.S. Pipkins, P.E. O' Donoghue, K. O' Sullivan, and H. Kawai to various parts of this report.

It is a pleasure to acknowledge the constant support, constructive criticism, and valuable insights, provided by Drs. V.A. Tischler and V.B. Venkayya of AFRL during the course of this project.

CHAPTER I

INTRODUCTION

1.1 Discrete source damage

A discrete source damage model is a stiffened panel with a straight crack. The preliminary design model, which is created for the preliminary design optimization of a major aircraft component (such as a wing or fuselage), does not contain any explicitly modeled damage. The preliminary design model must contain the necessary information for static analysis, including boundary conditions and loading conditions. When discrete source damage is specified in a master element of the preliminary design model, using the input data cards for the damage tolerance module, the damage tolerance model for the stiffened panel with a straight crack will be generated automatically by the damage tolerance module.

The discrete source damage model, generated by the damage tolerance module, can be subject to a tensile load and/or pressurization. The damage tolerance module can evaluate the stress intensity factors for the crack and their associated beta factors. A number of crack lengths can be specified for a single analysis. Fracture parameters are obtained for each of these cracks of different lengths.

The discrete source damage model is composed of a skin sheet which may be strengthened by an orthogonal grid of horizontal and/or vertical stiffeners. The horizontal stiffeners are called *stringers*, while the vertical stiffeners are called *frames*. Stiffeners may be connected with the skin sheet with rivets. The skin sheet may be a flat plate or a cylindrical shell. The crack may be horizontal or vertical; and it occurs over two bays. The stiffener which intersects with the crack may be broken.

After the analysis of the preliminary design model, the damage tolerance module generates the discrete source damage model, using the information obtained from the master elements and the input data cards that are related to the discrete source damage model. A global-local analysis is performed by the damage tolerance module to obtain the fracture parameters for the lead crack under the given loading condition.

In addition to the standard ASTROS input data cards for the description of the preliminary design model, the user has to specify the following information to analyze discrete source damage: the master element; the layout and properties of the panel; the damage; and the analysis control parameters using the bulk data cards. A detailed description of the bulk data cards introduced by the damage tolerance module are discussed in Chapter II. A brief summary with examples will be presented in this section.

A data card `DTCNTL` is required to specify the overall damage tolerance control parameters

for this damage. PNLELM and PNLSTF can be used to define the master element and the layout of the stiffeners on the panel, as well as the material properties of the stiffeners. If the panel is curved, the pressure applied over the master element is retrieved and applied on the skin of the discrete source damage model. Currently, only the pressure specified on the master element in terms of the PLOAD4 data card is supported.

Consider the following example of input data cards. A DTCNTL specifies that a discrete source damage DDSD with ID=2 is to be analyzed. The angle between the crack coordinate system and stress coordinate system of the master element is 90 degree ($= \pi/2 = 1.570796$). The master element is specified by the input card PNLELM with ID=3. The CDSD control card with ID=4 will be used. The CFTG and METHOD fields are not currently supported for the analysis of discrete source damage. Hence these fields should be left blank. The CDSD cards indicate that the discrete source damage is performed only for the ASTROS subcase with CASEID=4. Five cases with different crack lengths will be analyzed. The half crack length varies from 8.0 to 12.0 at equal intervals.

```
$DTCNTL |TYPE   |DMG    |PNLELM |ANGLE  |PNLSTF |CFTG   |CNTL   |METHOD |       |
DTCNTL  DDSD    2       3       1.5707963               4
$
$DDSD   |DMG    |VRTCL  |INTACT |       |       |       |       |       |       |
DDSD    2       NO      YES
$
$CDSD   |CNTL   |FRACMT |CASEID |MINCRK |MAXCRK |NSTEP  |       |       |       |
CDSD    4               4        8.0    12.0    5
$
$PNLELM |PNLELM |ETYPE  |EID    |       |       |       |       |       |       |
PNLELM  3       TRIA3   103
```

In this example, the DTCNTL card specifies that the stiffener layout is defined by the PNLSTF card with ID=3. An example of the corresponding PNLSTF card follows:

```
$PNLSTF |PNLSTF |MAT    |SKIN   |WIDTH  |LENGTH |RADIUS |BARSTR |BARFRM |CONT   |
$+PNLSTF|STRPCH |STRSPC |FRMPCH |FRMSPC |       |       |       |       |       |
PNLSTF  3       2       0.04    80.0    50.0    60.0    1       2       PNLSTF
+NLSTF  2.0     10.0    2.0     20.0
```

The skin thickness is defined in this PNLSTF as 0.04. The material property of the skin is defined in the standard MAT1 card with ID=2. Material properties of the stringers and frames are defined by the standard PBAR cards with ID=1 and 2. Stringer spacing and frame spacing, as well as rivet pitches on stringers and frames are also specified in this card (fields STRSPC, FRMSPC, STRPCH, and FRMPCH respectively).

1.2 Buckling and delamination

A buckling and delamination model (BUCKDEL) is a local model for the analysis of the buckling of a composite plate in the presence of delamination. The preliminary design model, which is created for the preliminary design optimization of a major aircraft component (such as a wing or fuselage), does not contain any explicitly modeled damage. The preliminary design model must contain the necessary information for static analysis, including boundary conditions and loading conditions. When a buckling/delamination control card is processed by the damage tolerance module, a buckling and delamination model is automatically generated using the input data cards for the damage tolerance module, and the static analysis result in the master element of the preliminary design model. The load factor for the buckling load for the preliminary design model is calculated using the BUCKDEL model.

The delamination in the BUCKDEL model is of an elliptical shape. The size of the delamination is specified using 2 parameters: the length and width of the delamination.

In additional to the standard ASTROS input data cards for the description of the preliminary design model, the user has to specify the following information to evaluate the buckling load in the presence of delamination: the master element, the size of the delamination, and the analysis control parameters. A detailed description of the bulk data cards introduced by the damage tolerance module is discussed in Chapter II. A brief summary with examples will be presented in this section.

```
$DTCNTL |TYPE   |DMG    |PNLELM |ANGLE  |PNLSTF |CFTG   |CNTL   |METHOD |       |
DTCNTL  DBKDEL  2       5       1.5707963               4
$
$DBKDEL |DMG    |WIDTH  |LENGTH |PLT    |NPLDL  |NPLBS  |       |       |       |
DBKDEL  2       8.0     4.0     0.005   6       10
$
$CBKDEL |CNTL   |CASEID |       |       |       |       |       |       |       |
CBKDEL  4       5
$
$PNLELM |PNLELM |ETYPE  |EID    |       |       |       |       |       |       |
PNLELM  5       QUAD4   101
```

Consider the above example of input data cards. A DTCNTL specifies that a BUCKDEL model (DBKDEL) with ID=2 is to be analyzed. The angle between the crack coordinate system and stress coordinate system of the master element is 90 degree ($= \pi/2 = 1.570796$). The master element is specified by the input card PNLELM with ID=5. The CBKDEL control card with ID=4 will be used. The CFTG and METHOD fields are not currently supported for the analysis of a BUCKDEL model. Hence these fields should be left blank. The CBKDEL cards indicated that the discrete source damage is performed only for the ASTROS subcase with CASEID=5. The DBKDEL describes the sizes and ply-layout of the panel. In this example, the delamination has width 8.0 and length 4.0.

The thickness of a ply is `0.005`. The number of plys in the delaminate region and the base region are 6 and 10, respectively.

In this example, the `DTCNTL` card specifies that the stiffener layout is defined by the `PNLSTF` card with ID=3. An example of the correponding `PNLSTF` card follows.

```
$PNLSTF |PNLSTF |MAT    |SKIN   |WIDTH  |LENGTH |RADIUS |BARSTR |BARFRM |CONT   |
$+PNLSTF|STRPCH |STRSPC |FRMPCH |FRMSPC |       |       |       |       |       |
PNLSTF  3       1               20.0    10.0
```

The width and length of the panel is defined in `PNLSTF`. The material property of the ply is specified by the card `MAT1` or `MAT8` with ID=1. The fields `SKIN`, `RADIUS`, `BARSTR`, `BARFRM`, `STRPCH`, `FRMPCH`, `STRSPC`, and `FRMSPC` are not used in the buckling and delamination problem. Hence these fields should be left blank.

1.3 Fatigue Crack Growth

This section shows an example of fatigue crack growth analysis.

1.3.1 Preliminary design model

For illustration purpose, a simple FEM model is used (see Fig. 1.1). The input card for the Finite Element Model is

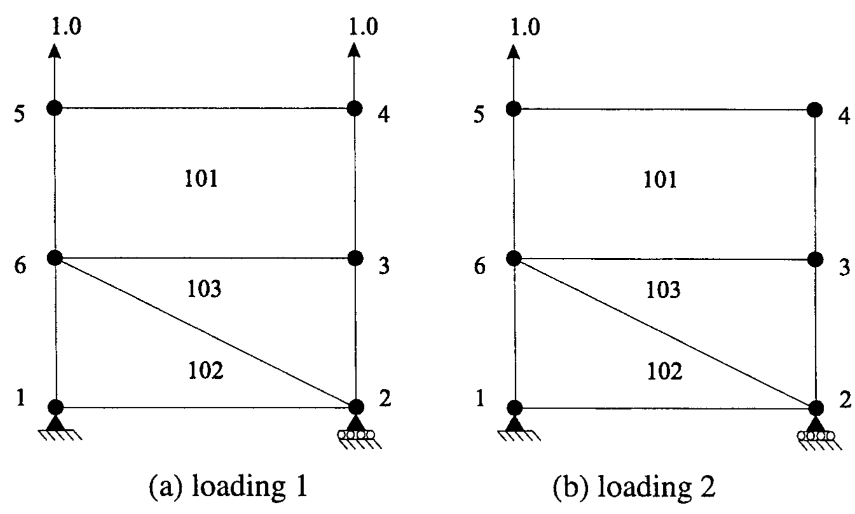

Figure 1.1: A simple FEM model

```
$
$ The FEM model: 6 nodes, 1 quad4 element and 2 tria3 elements
$
$ ---------------------------------------------------------------------------
$GRID   |    ID|       |  X1  |  X2  |  X3  |       |       |       |       |
$
GRID         1          0.000   0.000   0.000
GRID         2          2.000   0.000   0.000
GRID         3          2.000   1.000   0.000
GRID         4          2.000   2.000   0.000
GRID         5          0.000   2.000   0.000
GRID         6          0.000   1.000   0.000
$
$ ---------------------------------------------------------------------------
$CQUAD4 |   EID|   PID|    G1|    G2|    G3|    G4|       |       |       |
$
CQUAD4      101     100      3       4       5       6
$
$ ---------------------------------------------------------------------------
$CTRIA3 |   EID|   PID|    G1|    G2|    G3|       |       |       |       |
$
CTRIA3      102     100      1       2       6
CTRIA3      103     100      2       3       6
$
$ ===========================================================================
$
$   CQUAD4 and TRIA3 ELEMENTS HAVE 5 DEGREES OF FREEDOM PER NODE.  THERE IS NO
$   Z-ROTATION, SO THAT DEGREE OF FREEDOM IS ELIMINATED USING A GRDSET CARD.
$
$ ---------------------------------------------------------------------------
$SPC1   |   SID|     C|    G1|  THRU|    G2|       |       |       |       |
$
SPC1          6       6      1    THRU      6
$
$ ---------------------------------------------------------------------------
$SPC    |   SID|     G|     C|     D|       |       |       |       |       |
$
SPC           6       1      1     0.0
SPC           6       1      2     0.0
SPC           6       2      2     0.0
$
$ ===========================================================================
$
```

```
$  ALL CQUAD4 AND CTRIA3 ELEMENTS ARE .1 INCHES THICK
$
$ ------------------------------------------------------------------------------
$PSHELL |PID     |MID1    |T       |MID2    |12I/T3 |MID3    |        |        |        |
$
PSHELL  100     1       0.1     1       1.0     1
$
$ ==============================================================================
$
$  ALUMINUM   E=10.0E6 PSI  NU=.333
$
$ ------------------------------------------------------------------------------
$MAT1   |MID     |E       |G       |NU      |RHO     |        |        |        |        |
$
MAT1    1       10.0+6          .333    2.591-4
$
$ ==============================================================================
$
$ The two sets of load for loading case CASEID=5 and CASEID=6
$
$ ------------------------------------------------------------------------------
$FORCE  |     SID|       G|        |       F|      N1|      N2|      N3|        |        |
FORCE          1       4               1.0     0.0     1.0     0.0
FORCE          1       5               1.0     0.0     1.0     0.0
$
FORCE          2       5               1.0     0.0     1.0     0.0
$
```

In this example, the dimensions of this model are width = 2.0 and length = 2.0. The material used is aluminum: Youngs Modulus = 10.0E+6 and Poissons ratio = 0.333.

This model contains one quadrilateral and two triangular elements. The shell elements have a thickness of 0.1. All nodes are constrained against rotation about the z-axis. Node 1 has zero displacement in the x and y directions. Node 2 has zero displacement in the y direction. Two set of loading (ID=1 and 2) are specified.

1.3.2 Design Usage specification

The design usage of an aircraft is defined in terms of a sequence of flights. Each flight consists of a number of mission blocks. Each mission block consists of a number of missions. Each mission consists of a number of mission segments.

Following is the input data for the definition of design usage for illustration purposes.

```
$
$  flight sequences
$
$       define a flight life in terms of a sequence of flights
$
$ ------------------------------------------------------------------------------
$
$FLTSEQ |FLTSEQ |FLT    |REPEAT |FLT    |REPEAT |FLT    |REPEAT |       |CONT    |
$+FLTSEQ|FLT    |REPEAT |FLT    |REPEAT |FLT    |REPEAT |FLT    |REPEAT |ETC     |
$
FLTSEQ  1       1               2               3                       FLTSEQ
+LTSEQ  4               5               6
$
$ ==============================================================================
$
$  flight block sequences
$
$       define flights in terms of sequences of blocks
$
$ ------------------------------------------------------------------------------
$
$FLT    |FLT    |FLTBLK |REPEAT |FLTBLK |REPEAT |FLTBLK |REPEAT |       |CONT    |
$+FLT   |FLTBLK |REPEAT |FLTBLK |REPEAT |FLTBLK |REPEAT |FLTBLK |REPEAT |ETC     |
$
FLT     1       1               2       2       1
FLT     2       1       3       2
FLT     3       1       2       2
FLT     4       1       1       2
FLT     5       1               2       3
FLT     6       3               2       4
$
$ ==============================================================================
$
$  flight mission sequences
$
$       define blocks in terms of sequences of missions
$
$ ------------------------------------------------------------------------------
$
$FLTBLK |FLTBLK |FLTMSN |REPEAT |FLTMSN |REPEAT |FLTMSN |REPEAT |       |CONT    |
$+FLTBLK|FLTMSN |REPEAT |FLTMSN |REPEAT |FLTMSN |REPEAT |FLTMSN |REPEAT |ETC     |
$
FLTBLK  1       1               2
```

```
FLTBLK  2       3               2
FLTBLK  3       1               3
$
$ ==============================================================================
$
$  flight mission
$
$      define missions in terms of sequences of segments
$
$ ------------------------------------------------------------------------------
$
$FLTMSN |FLTMSN |FLTSGT |TIME   |FLTSGT |TIME   |FLTSGT |TIME   |       |CONT   |
$+FLTMSN|FLTSGT |TIME   |FLTSGT |TIME   |FLTSGT |TIME   |FLTSGT |TIME   |ETC    |
$
FLTMSN  1       1       6000.0  2       4500.0
FLTMSN  2       3       6000.0  2       300.0
FLTMSN  3       1       1001.0
$
$ ==============================================================================
$
$  flight segments
$
$      load spectrum and associated period for each segment
$
$ ------------------------------------------------------------------------------
$
$FLTSGT |FLTSGT |FLTSPC |OCCEXC |PERIOD |       |       |       |       |       |
$
FLTSGT  1       1               100.0
FLTSGT  2       1               200.0
FLTSGT  3       2               50.0
$
$ ==============================================================================
$
$  load spectrums
$
$      number of cycles for each loading case in the spectrum within the
$      period for the specific segment
$
$ ------------------------------------------------------------------------------
$
$FLTSPC |FLTSPC |NUMTIM |CASEID |SCALE  |NUMTIM |CASEID |SCALE  |       |CONT   |
$+FLTSPC|       |NUMTIM |CASEID |SCALE  |NUMTIM |CASEID |SCALE  |       |ETC    |
```

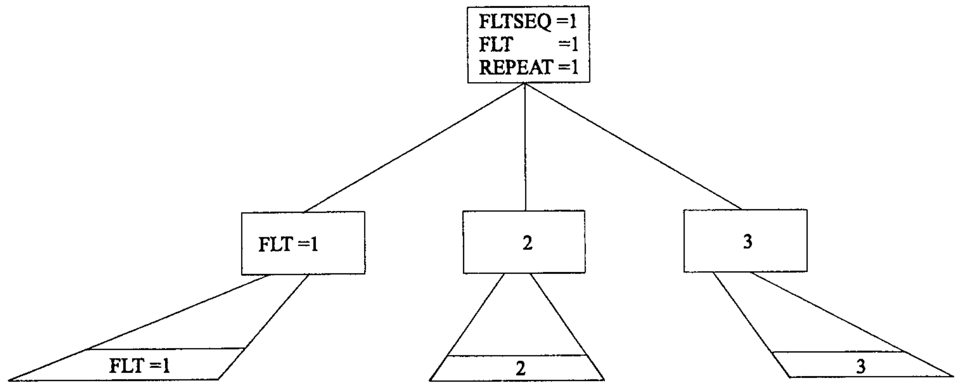

Figure 1.2: Define a sequence of flights

```
$
$ occurance
$
FLTSPC   1        50.0    5      0.1      50.0    6      2.4             CONT
+ONT              200.0   6      1.2      300.0   5      -1.2
FLTSPC   2        50.0    6      -0.1     50.0    6      1.4             CONT
+ONT              250.0   6      1.2      100.0   5      1.2
$
```

As shown in the above input data, FLTSEQ defines a sequence of flights by specifying the IDs for the FLT data cards. Each flight can be repeated for a number of times, as illustrated in Fig. 1.2

FLT defines a flight by specifying a sequence of the IDs for the FLTBLK data card. Each mission block can be repeated for a number of times, as illustrated in Fig. 1.3.

FLTBLK defines a flight block by specifying a sequence of the IDs for the FLTMSN data card. Each mission can be repeated for a number of times, as illustrated in Fig. 1.4.

FLTMSN defines a flight mission by specifying a sequence of the IDs for the FLTSGT data card. The amount of flight time for each mission segment is specified with the ID, as illustrated in Fig. 1.5.

FLTSGT defines detailed information about a flight segment. A flight spectrum ID (FLTSPC) is associated with each of the flight segment in order to specify the occurrence/exceedance spectrum, as well as the period of time during which the number of occurrence/exceedance is counted.

Each flight spectrum consists a number of loading cases FLTSPC. With scale factors, ASTROS subcase IDs (CASEID) are associated with each loading case.

1.3.3 Damage definition and control parameters

The input card for the definition of damage, as well as the control parameters for the fatigue analysis, follows.

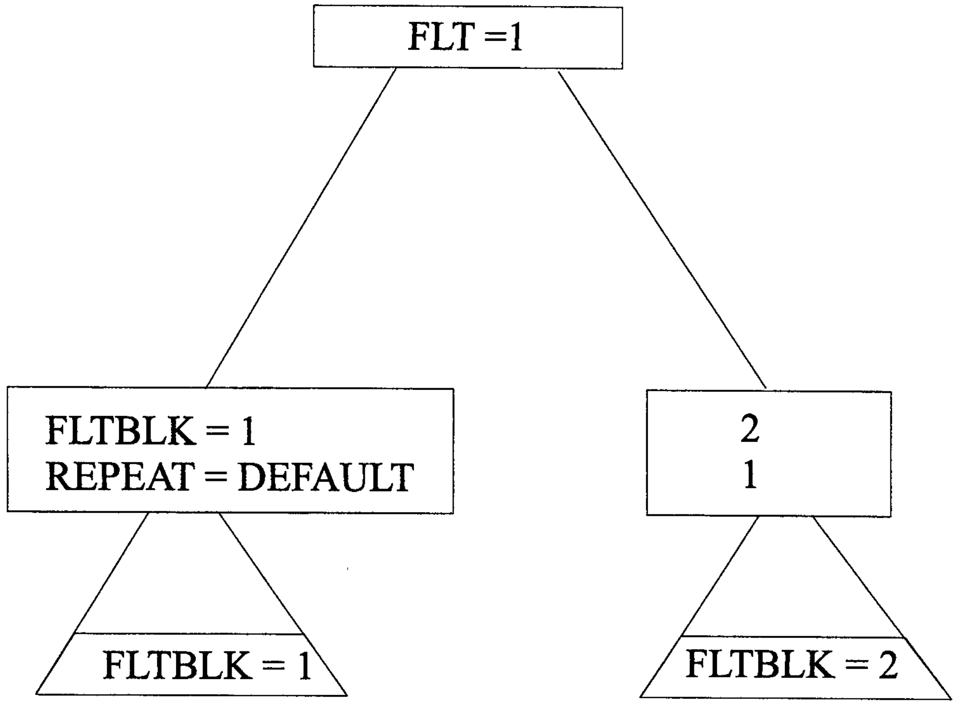

Figure 1.3: Define a flight

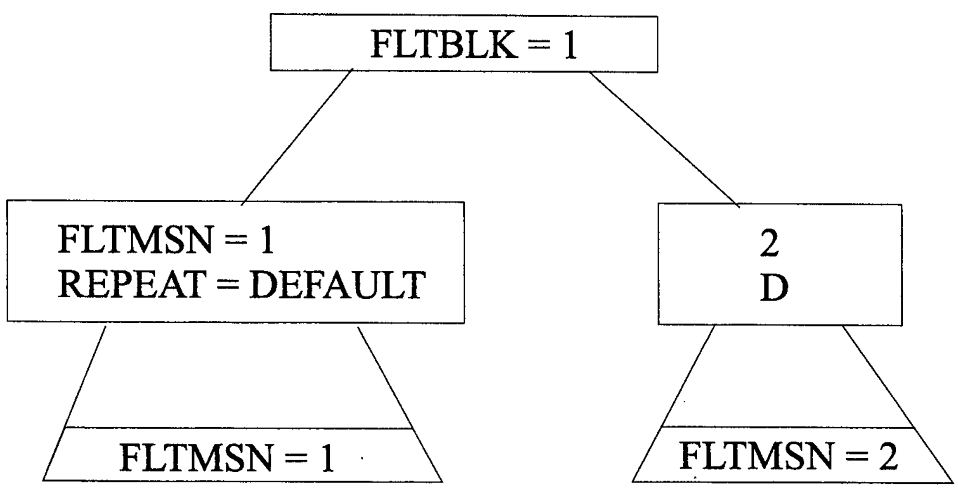

Figure 1.4: Define a mission block

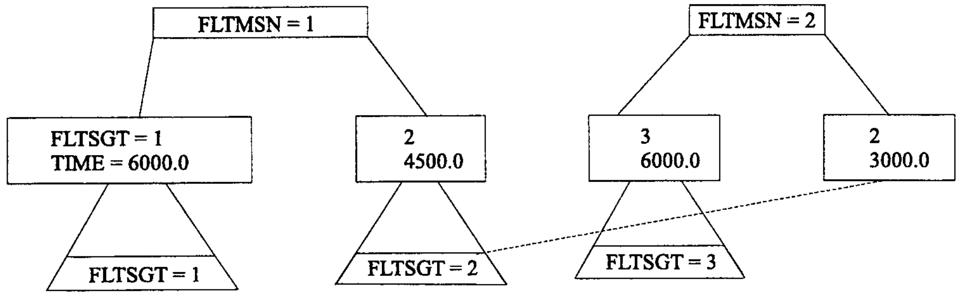

Figure 1.5: Define a mission

```
$ ===========================================================================
$
$  DT control cards
$
$       ANGLE= PI/2 FOR PNLELM 12 SINCE THE LOCAL COORDINATE
$       IS NOT THE SAME AS THE GLOBAL COORDINATE
$
$ ---------------------------------------------------------------------------
$
$DTCNTL |TYPE   |DMG    |PNLELM |ANGLE  |PNLSTF |CFTG   |CNTL   |METHOD |       |
$
DTCNTL  DTWC     7      12      1.570796        1       1
DTCNTL  DTWC    21      22      0.0     3               2       BETA
$
$ ===========================================================================
$
$  Define the size of the cracks
$
$ ---------------------------------------------------------------------------
$
$DTWC   |DMG    |A      |       |       |       |       |       |       |       |
DTWC     7      0.1
DTWC    21      0.1
$
$ ===========================================================================
$
$  analysis options
$
$ ---------------------------------------------------------------------------
$
$CTWC   |CNTL   |CASEID |PRINT  |       |       |       |       |       |       |
```

```
$
CTWC    1       6       YES
CTWC    2       5       NO
$
$
$ ===============================================================================
$
$  pre-calculated beta factors
$
$ -------------------------------------------------------------------------------
$
$SIF    |DMG    |ID     |       |       |       |BETA1  |BETA2  |BETA3  |       |
$
SIF     21      1                               1.2     1.3
$
$ ===============================================================================
$
$  master elements
$
$ -------------------------------------------------------------------------------
$
$PNLELM |PNLELM |ETYPE  |EID    |       |       |       |       |       |       |
$
PNLELM  12      QUAD4   101
PNLELM  22      TRIA3   102
$
$ ===============================================================================
$
$  panel size information
$
$ -------------------------------------------------------------------------------
$
$PNLSTF |PNLSTF |MAT    |SKIN   |WIDTH  |LENGTH |RADIUS |BARSTR |BARFRM |       |
$
PNLSTF  3                       10.0    20.0
$
$ ===============================================================================
$
$  fatigue analysis control
$
$ -------------------------------------------------------------------------------
$
$CFTG   |CFTG   |FRACMT |FLTSEQ |REPEAT |VSTEP  |DN     |       |       |       |
```

```
$
CFTG    1       1       1       0.001   0.01    10.0
$
$ ==============================================================================
$
$  Coefficients for Paris' law
$
$ ------------------------------------------------------------------------------
$
$FRACMT |FRACMT |KIC    |KTH    |COEF   |EXPM   |EXPN   |EXPP   |EXPQ   |       |
$
FRACMT  1       90.0    20.0    3.0E-8  3.0
$
```

In this example, two through wall cracks DTWC are defined. No PNLSTF is associated with DTWC 7. Therefore, the size of the local model will be extracted from the size of the master element. It's master element is a QUAD4 element, specified by the card PNLELM with ID=12.

An example of the solution packet is the following.

```
SOLUTION
  TITLE   =ASTROS-DT/KSI example problem
  SUBTITLE=DT
  PRINT STRESS=ALL
  ANALYZE
     BOUNDARY SPC=6, BCID=2
        STATICS 5 ( MECH=1 )
          LABEL=STATIC ANALYSIS OF A FLAT SHEET SUBJECTED TO UNIFORM LOAD
        STATICS 6 ( MECH=2 )
          LABEL=STATIC ANALYSIS OF A FLAT SHEET SUBJECTED TO NONUNIFORM LOAD
END
```

CHAPTER II

BULK DATA DESCRIPTIONS

This chapter summarizes the bulk data entries introduced by the damage tolerance module. The user-specified input information for the damages tolerance module is provided to the system through these bulk data cards.

It is assumed that the reader is familiar with the ASTROS bulk data cards, which are directly analogous to the NASTRAN bulk data cards.

A summary of the data cards introduced by the DT module is presented as follows.

CATEGORY	ENTITIES
Flight life definition	FLTSEQ, FLT, FLTBLK, FLTMSN, FLTSGT, FLTSPC
Damage definition	DTWC, DHLTWC, DSF, DHLSF, DCVC, DHLCVC, DDSD, DBKDEL, CVPATH
Panel definition	PNLELM, PNLSTF
Control Parameters	DTCNTL, CFTG, CTWC, CHLTWC, CSF, CHLSF, CCVC, CHLCVC, CDSD, CBKDEL
Fracture Properties	FRACMT, SIF

Input Data Entry: `DTWC` Through wall crack

Description: Defines the dimensions of a through wall crack

Format and Example:

DTWC	DMG	A							

DTWC	2	1.2							

Field	Contents
DMG	Crack ID (DTWC). (Integer > 0)
A	The half length (a) of the crack. (Real > 0.0)

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system.

2. Both crack tips are assumed to have the same SIFs.

3. The crack tip ID for the left crack is 1.

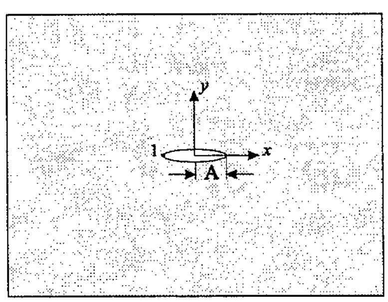

Figure 2.1: A through wall crack

Input Data Entry: DHLTWC Rivet hole cracks

Description: Defines the dimensions of the cracks emanating from a rivet hole

Format and Example:

DHLTWC	DMG	A1	A2	RADIUS					

DHLTWC	1	0.2	0.3	0.5					

Field	Contents
DMG	Crack ID (DHLTWC). (Integer > 0)
A1	The length (a_1) for the crack to the left of the rivet hole. (Real $\geq$ 0.0, Default= 0.0)
A2	The length (a_2) for the crack to the right of the rivet hole. (Real $\geq$ 0.0, Default= 0.0)
RADIUS	The radius (r) of the rivet hole. (Real > 0.0)

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $a = r + (a_1 + a_2)/2$.

2. The crack tip ID for the crack A1 is 1.

3. The crack tip ID for the crack A2 is 2.

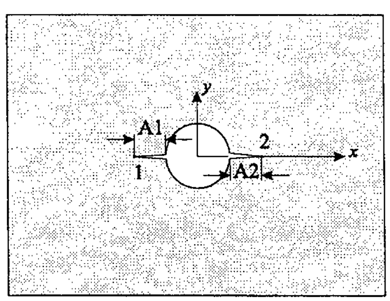

Figure 2.2: Two cracks emanating from a hole

Input Data Entry: `DSF` Surface flaw

Description: Defines the dimensions of a semi-elliptical/circular surface flaw

Format and Example:

DSF	DMG	A	B						

DSF	2	0.2	0.1						

Field	Contents
DMG	Crack ID (DSF). (Integer > 0)
A	Half Length (a) of the crack. (Real > 0)
B	Depth (b) of crack. (Real > 0)

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y \sqrt{\pi \bar{a}}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy} \sqrt{\pi \bar{a}}}, \qquad \beta_3 = \frac{K_{III}}{\sigma_{xy} \sqrt{\pi \bar{a}}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $\bar{a} = \min(a, b)$.

2. The crack tip ID for the points on the crack front are shown in the Fig. 2.3

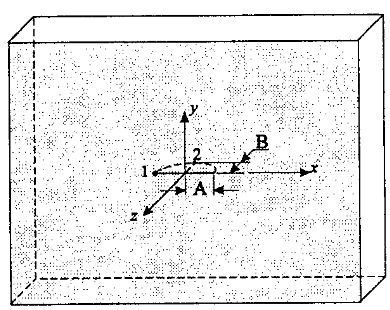

Figure 2.3: A surface flaw of the shape of semi-ellipse/circle

Input Data Entry: `DHLSF` Corner cracks

Description: Defines the dimensions of corner cracks emanating from a rivet hole

Format and Example:

DHLSF	DMG	A	B	RADIUS					

DHLSF	2	0.4	0.2	1.0					

Field	Contents
DMG	Crack ID (DHLSF). (Integer > 0)
A	Length (a) of the crack. (Real > 0)
B	Depth (b) of the crack. (Real > 0)
RADIUS	The radius (r) of the rivet hole. (Real > 0.0)

Remarks:

1. Two corner cracks ementating from both sides of the hole. They are symmetric about the y-axis.

2. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi\bar{a}}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi\bar{a}}}, \qquad \beta_3 = \frac{K_{III}}{\sigma_{xy}\sqrt{\pi\bar{a}}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $\bar{a} = \min(a, b)$.

3. The crack tip ID for the points on the crack front are shown in the Fig. 2.4

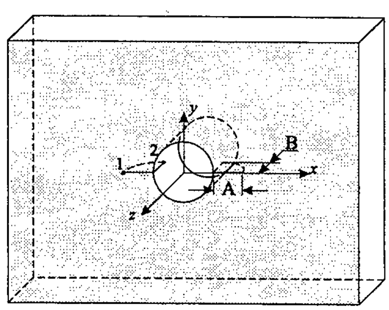

Figure 2.4: Two corner cracks emanating from a hole

Input Data Entry: `DCVC` Curved cracks

Description: Defines the dimensions of a curved crack

Format and Example:

DCVC	DMG	PATH							
DCVC	2	1							

Field	Contents
DMG	Crack ID (DCVC). (Integer > 0)
PATH	Path ID (CVPATH) for the definition of the crack. (Integer > 0)

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the coordinate system for the equivalent crack. The equivalent crack is defined by the straight line connecting the two crack tips of the curved crack. a is the half length of the equivalent crack.

2. The crack tip ID for the first crack tip (corresponding to the first point in PATH) is 1; and the crack tip ID for the second crack tip (corresponding to the last point in PATH) is 2.

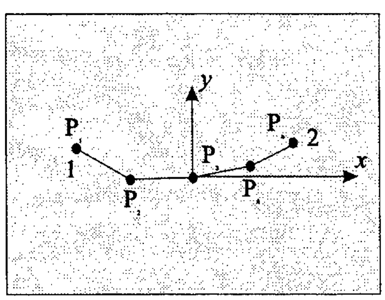

Figure 2.5: A curved crack

Input Data Entry: DHLCVC Rivet hole curved cracks

Description: Defines the dimensions of the curved cracks emanating from a rivet hole

Format and Example:

DHLCVC	DMG	PATH1	PATH2	RADIUS					

DHLCVC	1	2	3	0.5					

Field	Contents
DMG	Crack ID. (Integer > 0)
PATH1	Path ID (CVPATH) for the definition of the first crack. (Integer ≥ 0)
PATH2	Path ID (CVPATH) for the definition of the second crack. (Integer ≥ 0)
RADIUS	The radius (r) of the rivet hole. (Real > 0.0)

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the coordinate system for the equivalent crack. The equivalent crack is defined by the straight line connecting the two crack tips of the curved crack. a is the half length of the equivalent crack.

2. The crack tip ID for the first crack tip is 1; and the crack tip ID for the second crack tip is 2.

3. Both crack paths mush be defined such that the last points are the crack tips.

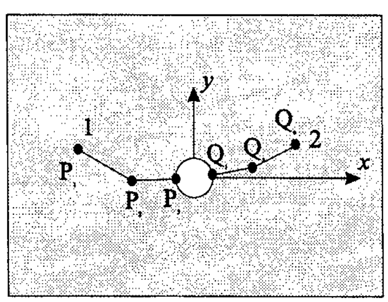

Figure 2.6: The curved cracks emanating from a rivet hole

Input Data Entry: DDSD Damage Data of Discrete Source Damage Problem

Description: This data entry describes the characteristics of the single lead crack as discrete source damage. The crack is placed at the center bay of the panel, either horizontally or vertically. The stiffeners which intersect with the crack may or may not be broken.

Format and Example:

DDSD	DMG	VRTCL	INTACT						

DDSD	1	NO	YES						

Field	Contents
DMG	This field represents the data entry ID of this data entry. (Integer $>$ 0)
VRTCL	Defines the orientation of the crack.(Default =NO)
INTACT	Describes whether the stiffeners or frames are intact or broken by the crack. (Default =NO)

Remarks:

1. VRTCL, this field represents whether the crack orientation is vertical or horizontal.

   To analyze with the user defined settings, enter 'YES'. This will define the crack as vertical, i.e., the crack is parallel with the frames. If the panel is curved, the crack is known as the circumferential crack.

   To analyze with the default settings, leave value as 'NO'. This will define the crack as horizontal, i.e., the crack is parallel with the stringers. If the panel is curved, the crack is known as the longitudinal crack.

2. INTACT. This field represents whether the stiffeners are intact or broken by the crack

   To analyze with the user defined settings, enter 'YES'. This will define the stiffeners or the frames to be broken. In the case of a vertical crack, the stiffeners which will intersect with the crack will be broken. In the case of a horizontal crack, the frames which will intersect with the crack will be broken.

   To analyze with the default settings, leave value as 'NO'. This will define both the stiffeners and the frames to be intact with the skin sheet.

Input Data Entry: `DBKDEL` Definition of damage in buckling and delamination case

Description: This data entry describes the damage due to delamination. The delaminate region can be placed at the center bay of the panel. The shape of the delaminate region is an ellipse. This information is represented by diameters of two axis. Information about the composite laminate is also specified.

Format and Example:

DBKDEL	DMG	WIDTH	LENGTH	PLT	NPLDL	NPLBS			
DBKDEL	2	4.0	2.0	0.005	8	16			

Field	Contents
DMG	This field represents the data entry ID of this data entry. (Integer > 0)
WIDTH	Width of the delaminate region. (Real > 0.0)
LENGTH	Length of the delaminate region. (Real > 0.0)
PLT	Thickness of a ply. (Real > 0.0)
NPLDL	Number of plies of the delaminate region. (Integer ≥ 0) (Default $= 0$)
NPLBS	Number of plies of the base region (Integer > 0)

Remarks:

1. `WIDTH` represents the width of the delaminate region in the horizontal direction. The delaminate region is an ellipse, and the width is the diameter of the ellipse along the horizontal axis.

   To analyze with the user defined settings, enter a value greater than zero. This value defines the width of the delaminate in the horizontal direction.

2. `LENGTH` represents the length of the delaminate region in the vertical direction. The delaminate region is an ellipse, and the length is the diameter of the ellipse along the vertical axis.

   To analyze with the user defined settings, enter a value greater than zero. This value defines the length of the delamination in the vertical direction.

3. `NPLDL` represents the number of plys of the delaminate region.

   To analyze with the user defined settings, enter a value greater than zero. The panel has the delaminate region, and this value will define the number of plys of the delaminate region. The number of plys of the undelaminate region is the sum of `NPLBS` and `NPLDL`.

   To analyze with the default settings, leave the value as zero. The panel does not have a delaminate region.

4. NPLBS represents the number of plys of the base region.

   To analyze with the user defined settings, enter a value greater than zero. This value will define the number of plys of the base region. If NPLDL is zero, then the panel does not have delaminate region, and this value will define the number of plys of the undelaminated region. Otherwise, the number of plys of the undelaminate region is the sum of NPLBS and NPLDL.

Input Data Entry: `CVPATH` Cracking path

Description: Defines the cracking path of a curved crack

Format and Example:

CVPATH	ID	X1	Y1	X2	Y2	X3	Y3		CONT
+ONT	X4	Y4	X5	Y5	X6	Y6	X7	Y7	ETC

CVPATH	1	-0.1	0.05	-0.05	0.0	0.0	0.0		

Field	Contents
ID	Cracking path ID (CVPATH). (Integer > 0)
Xn	The x-coordinates (x_n) of the points on the path in the crack coordinate system. (Real)
Yn	The y-coordinates (y_n) of the points on the path in the crack coordinate system. (Real)

Remarks:

1. Points on the path must be defined in the sequence according to their position on the path.
2. The crack tip must be the last point for the path that has only one crack tip.

Input Data Entry: FLTSEQ Flight Sequence

Description: Defines the load history a structure is subjected to over its life (often called the design usage) in terms of a series of flights

Format and Example:

FLTSEQ	ID	FLT1	REPEAT1	FLT2	REPEAT2	FLT3	REPEAT3		CONT
+ONT	FLT4	REPEAT4	FLT5	REPEAT5	FLT6	REPEAT6	FLT7	REPEAT7	ETC

FLTSEQ	2	2	3	4		6	3		

Field	Contents
ID	Flight Sequence ID (FLTSEQ). (Integer > 0)
FLTn	Flight ID (FLT). (Integer > 0)
REPEATn	Repeat this many times. (Integer > 0, Default $= 1$)

Remarks:

1. A series of flights, sharing the same FLTSEQ ID, defines one design life of an aircraft.
2. The series of flights should be repeated whenever possible to reduce the system requirements (file space) necessary to store the load history data.

Input Data Entry: FLT Flight

Description: Describes the load history of a Flight in terms of a series of mission blocks

Format and Example:

FLT	ID	FLTBLK1	REPEAT1	FLTBLK2	REPEAT2	FLTBLK3	REPEAT3		CONT
+ONT	FLTBLK5	REPEAT5	FLTBLK6	REPEAT6	FLTBLK7	REPEAT7	FLTBLK8	REPEAT8	ETC

FLT	5	1	5	2	3				

Field	Contents
ID	Flight ID (FLT). (Integer > 0)
FLTBLKn	Block ID (FLTBLK). (Integer > 0)
REPEATn	Repeat this many times. (Integer > 0, Default = 1)

Remarks:

1. A series of mission blocks, sharing the same FLT ID, defines a flight.
2. When defining the design of an aircraft, a Flight typically consists of 500 or 1000 flight hours. The actual time duration each Flight represents is determined from the build up of Mission Segments, Missions, and Mission Blocks as specified by the user.

Input Data Entry: FLTBLK A sequence of missions

Description: Defines a mission block in terms of a series of Missions with a duration

Format and Example:

FLTBLK	ID	FLTMSN1	REPEAT1	FLTMSN2	REPEAT2	FLTMSN3	REPEAT3		CONT
+ONT	FLTMSN4	REPEAT4	FLTMSN5	REPEAT5	FLTMSN6	REPEAT6	FLTMSN7	REPEAT7	ETC

FLTBLK	1	5	3	4	2				

Field	Contents
ID	Block ID (FLTBLK). (Integer > 0)
FLTMSNn	Mission ID (FLTMSN). (Integer > 0)
REPEATn	Repeat many times. (Integer > 0, Default = 1)

Remarks:

1. A series of missions, sharing the same FLTMSN ID, defines a flight block.

Input Data Entry: FLTMSN Flight mission

Description: Defines the load history in terms of a series of Mission Segments with a specified duration

Format and Example:

FLTMSN	ID	FLTSGT1	TIME1	FLTSGT2	TIME2	FLTSGT3	TIME3		CONT
+ONT	FLTSGT5	TIME5	FLTSGT6	TIME6	FLTSGT7	TIME7	FLTSGT8	TIME8	ETC

FLTMSN	4	4	3000	4	5000				

Field	Contents
ID	Mission ID (FLTMSN). (Integer > 0)
FLTSGTn	Flight Segment ID (FLTSGT). (Integer > 0)
TIMEn	Flight time for this mission segment n. (Real > 0.0)

Remarks:

1. A series of mission segments, sharing the same FLTMSN ID, defines a mission.

Input Data Entry: FLTSGT Mission Segment

Description: Defines the load history of a Mission Segment when there is only one load case (maneouver) in each level of the Mission Segment Load Spectrum

Format and Example:

FLTSGT	ID	FLTSPC	OCCEXC	PERIOD					

FLTSGT	2	OCC	200	4					

Field	Contents
ID	Segment ID (FLTSGT). (Integer > 0)
FLTSPC	Spectrum ID (FLTSPC). (Integer > 0)
OCCEXC	Occurance or Exceedance. (OOC or EXC, default= OOC)
PERIOD	The flight time on which the spectrum is based (REAL > 0.0, Default = 1000.0)

Remarks:

1. OCCEXC indicates whether FLTSPC is an occurance spectrum or an excedence spectrum.
2. The occrurance/excedence numbers in the spectrum FLTSPC are based on the flight time PERIOD.

Input Data Entry: FLTSPC Flight Spectrum

Description: Defines the flight specturm in terms of a collection of loading ASTROS loading cases

Format and Example:

FLTSPC	ID	NUM1	CASEID1	SCALE1	NUM2	CASEID2	SCALE2		CONT
+ONT		NUM3	CASEID3	SCALE3	NUM3	CASEID4	SCALE4		ETC

FLTSPC	1	50.0	5	0.1	50.0	6	2.4		CONT
+ONT		200.0	6	1.2	300.0	5	-1.2		

Field	Contents
ID	Spectrum ID (FLTSPC). (Integer > 0)
NUMn	Number of occurance/exceedence for the loading condition n. (Real > 0.0
CASEIDn	ASTROS CASEID for the loading condition n. (Integer > 0
SCALEn	Scaling factor for the loading condition n. (Real)

Remarks:

1. Number of occurance/exceedence is based on the PERIOD defined in FLTSGT.

Input Data Entry: PNLELM Definition of the master element of a panel

Description: This data entry describes the master element of the panel. The master element is one of the shell elements in the global model. This element contains the panel described in the PNLSTF data entry and also contains information for the intermediate and/or the local model. The boundary conditions of the intermediate or the local model are obtained from the analysis results on this element. If there is any information missing from the panel's data entries, the program will automatically derive this missing information from the master element.

Format and Example:

PNLELM	ID	ETYPE	EID						

PNLELM	2	QUAD4	1						

Field	Contents
ID	This field represents the data entry ID of this data entry. (Integer > 0)
ETYPE	The type of the master element. (CHARACTER) Currently available choices: QUAD4, TRIA3.
EID	The element ID of the master element (Integer > 0)

Remarks:

1. None.

Input Data Entry: PNLSTF Definition of a panel and stiffner layout on the panel

Description: This data entry describes the skin sheet and the stiffeners of the panel. The stiffener information is relevant to the discrete source damage problem only. The panel is referred from the master element. The master element is one of the shell elements in the global model, and it contains the entire panel. In the dicrete source damage problems, this data entry represents the skin sheet and the stiffeners information of the intermeidate and the local model. In the other problems, it represents the skin sheet information of the local model.

Format and Example:

PNLSTF	PNLSTF	MAT	SKIN	WIDTH	LENGTH	RADIUS	BARSTR	BARFRM	CONT
+ONT	STRPSCH	STRSPC	FRMPCH	FRMSPC					

PNLSTF	1	10	0.04	40.00	50.00	75.00	21	22	CONT
+ONT	1.0	4.0	1.0	10.0					

Field	Contents
PNLSTF	This field represents the data entry ID of this data entry. (Integer > 0)
MAT	Material property ID of the skin sheet of the panel (Integer ≥ 0) (Default $= 0$)
SKIN	Thickness of the panel's skin (Real ≥ 0.0) (Default $= 0.0$)
WIDTH	Width of the panel. (Real ≥ 0.0) (Default $= 0.0$)
LENGTH	Length of the panel. (Real ≥ 0.0) (Default $= 0.0$)
RADIUS	Radius of the panel. (Real ≥ 0.0) (Default $= 0.0$)
BARSTR	Bar geometrical property ID of the stringers of the panel (Integer ≥ 0) (Default $= 0$)
BARFRM	Bar geometrical property ID of the frames of the panel (Integer ≥ 0) (Default $= 0$)
STRPSCH	Rivet pitch along the stringers of the panel (Real > 0.0)
STRSPC	Stringer spacing of the panel (Real ≥ 0.0) (Default $= 0.0$)
FRMPCH	Rivet pitch along the frames of the panel (Real > 0.0)
FRMSPC	Frame spacing of the panel (Real ≥ 0.0) (Default $= 0.0$)

Remarks:

1. In the case of discrete source damage problems, the following criteria is applied:

   The intermediate model covers the entire panel. The boundary conditions of the intermediate model are developed from the global analysis of the master element. The local model is a portion of the intermediate model.

   The panel can be flat or curved. If curved, the panel is regarded as cylindrical, the horizontal direction of the panel becomes the longitudinal direction, while the vertical direction becomes the circumferential direction.

   The horizontal stiffeners are the stringers, and the vertical stiffeners are the frames.

   Horizontal crack: The number of stringer bays must be odd and the number of frame bays must be even. The horizontal crack must be placed between two stringers, and it must cross the central frame, which can be broken.

   Vertical crack: The number of frames bays must be an odd number and the number of stringer bays must be an even number. The vertical crack must be placed between two frames, and it must cross with the center stringer, which can be broken.

   In the other problems, only skin sheet data are relevant. The data are used for the local model.

2. `MAT`: This field represents the material property ID of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of buckling and delamination problems, the selected `MAT1` or `MAT8` data entry will be used for the material properties of the ply of the skin sheet as a composite lamina. In the other problems, the selected MAT1 data entry will be used for the skin sheet.

   To analyze with the default settings, the leave value as zero. The skin sheet's material properties will be obtained from the master element.

3. `SKIN`: This field represents the thickness of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of buckling and delamination problems, this field value is ignored, and the value in the DBKDEL data entry is used instead of it. In the other problems, this field value will define the thickness of the skin sheet.

   To analyze with the default settings, leave the value as zero. The skin sheet's thickness will be obtained from the master element.

4. `WIDTH`: This field represents the width of the panel.

   To analyze with the user defined settings, enter a value greater than zero. In the case of discrete source damage problems, this field value will define the width of the panel at the intermediate stage. If the total distance between the two end frames is greater than the entered value, the width will automatically adjust based on the FRMSPC field. In the other problems, this field value will define the width of the panel at the local stage.

   To analyze with the default settings, leave the value as zero. The skin sheet's thickness will be obtained from the master element.

5. `LENGTH`: This field represents the length of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of discrete source damage problems, this field value will define the length of the panel at the intermediate stage. If the total distance between the two end stringers is greater than the entered value, the length will automatically adjust based on the STRSPC field. In the other problems, this field value will define the width of the panel at the local stage.

   To analyze with the default settings, leave the value as zero. The skin sheet's length will be obtained from the master element.

6. `RADIUS`: This field represents the radius of the curved panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The panel becomes curved, and this field value will define the radius of the panel at the intermediate stage.

   To analyze with the default settings, leave the value as zero. The panel becomes flat.

7. `BARSTR`: This field represents the bar geometrical property ID of the stringers of the panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The selected PBAR data entry will define the bar geometrical properties of the beam elements of the stringers at the intermediate stage.

   To analyze with the default settings, leave the value as zero. This will assume that the panel has no stringers.

8. `BARFRM`: This field represents the bar geometrical property ID of the frames of the panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The selected PBAR data entry value will define the bar geometrical properties of the beam elements of the frames at the intermediate stage.

   To analyze with the default settings, leave the value as zero. This will assume that the panel has no frames.

9. `STRPSCH`: This field represents the rivet pitch along the stringers, i.e. the distance between two rivets along the stringers. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. To connect the rivets to the stringers and the skin sheet, enter a value which is less than the value of the FRMSPC field, the frame spacing. To have the stringers not connected to the skin, enter a value which is greater than the value of the FRMSPC field. This allows the stringer to be indirectly connected to the skin via the frame and stringer intersection.

   Note, the size of the finite element model at the intermediate stage depends on the rivet spacing.

10. STRSPC: This field represents the stringer spacing of the panel, i.e., the distance between two stringers. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. This field value will define the stringer spacing.

    To analyze with the default settings, leave the value as zero. This will assume that the panel has no stringers.

    This field also affects the existence of rivet connections between the frames and the skin. If there are rivets on the frames, frame rivet pitch, FRMPCH, must be less than STRSPC.

11. FRMPCH: This field represents the rivet pitch along the frames of the panel, i.e., the distance between any two rivets on the frames. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. To connect the rivets to the frames and the skin, enter a value which is less than the value of the STRSPC field, the stringer spacing. To have the frames not connected to the skin, enter a value which is greater than the value of the STRSPC field. This allows the frame to be indirectly connected to the skin via the frame and stringer intersection.

    Note, the size of the finite element model at the intermediate stage depends on the rivet spacing.

12. FRMSPC: This field represents the frame spacing of the panel, i.e., the distance between two stringers. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. This field value will define the frame spacing.

    To analyze with the default settings, leave the value as zero. This will assume that the panel has no frames.

    This field also affects the existence of the rivet connections between the frames and the skin. If there are rivets on the stringers, stringer rivet pitch, STRPCH, must be less than FRMSPC.

Input Data Entry: DTCNTL Control parameters for DT Analysis

Description: Describes the control parameters required for Damage Tolerance Analysis

Format and Example:

DTCNTL	TYPE	DMG	PNLELM	ANGLE	PNLSTF	CFTG	CNTL	METHOD	

DTCNTL	DDSD	1	5	1.57			2	FEAM	

Field	Contents
TYPE	The type of damage to be analyzed. Currently available choices are: DDSD, DBKDEL, DHLSF, DSF, DTWC, DHLTWC, DCVC, and DHLCVC.
DMG	ID for the damage of type TYPE. (Integer > 0)
PNLELM	ID for the master element definition (PNLELM). (Integer > 0)
ANGLE	The angle between the crack coordinate system and the element stress coordinate system. (Real ≥ 0.0, Default $= 0.0$)
PNLSTF	Panel ID (PNLSTF). (Integer ≤ 0, Default $= 0$)
CFTG	ID (CFTG) for the parameter that controls the fatigue analyses. (Integer ≤ 0, Default $= 0$)
CNTL	Damage dependent control card ID (CDSD, CBKCEL, CHLSF, CSF, CTWC, CHLTWC, CCVC, CHLCVC). (Integer ≥ 0, Default $= 0$)
METHOD	The analysis method. (Character, Default=FEAM)

Remarks:

1. The damage ID DMG must be unique among DDSD, DBKDEL, DHLSF, DSF, DTWC, DHLTWC, DCVC, and DHLCVC.

2. ANGLE is used to determine the orientation of the stiffeners or the cracks.

3. METHOD can be one of the following keywords INF, BETA or FEAM. Available options for different type of damages are as follows.

	DTWC	DHLTWC	DCVC	DHLCVC	DSF	DHLSF	DDSD	DBKDEL
INF	√	√						
BETA	√	√	√	√	√	√		
FEAM	√	√	√	√	√	√	√	√

INF: use the analytical solution for the crack in the infinite sheet. BETA: use pre-calculated beta factors FEAM: use Finite Element Alternating Method

4. SIF must be uniquely defined for each crack tip if the user choses to calculate the SIF using beta factors.

Input Data Entry: CFTG Fatigue Damage

Description: Define the fatigue damage module

Format and Example:

CFTG	ID	FRACMT	FLTSEQ	REPEAT	VSTEP	DN			
CFTG	1	10	5	2.5	0.1	0.1			

Field	Contents
ID	Control ID (Integer > 0)
FRACMT	Fatigue material properties. (Integer > 0)
FLTSEQ	Life ID. (Integer > 0)
REPEAT	Repeat Number. (Real > 0) (Default = 1.0)
VSTEP	SIF update frequency (in terms of the amount of crack growth). (Real > 0) (Default = 0.1)
DN	Fatigue crack growth step (in terms of number of cycles) (Real > 0) (Default = 0.1)

Remarks:

1. REPEAT: number of times that design usage (LIFE) should be repeated
2. VSTEP: percentage of crack growth before the SIF is updated

Input Data Entry: `CTWC` Analysis control for a through wall crack

Description: Defines the control parameters for the analysis of a through wall crack

Format and Example:

CTWC	CNTL	CASEID	PRINT						

CTWC	3	1	YES						

Field	Contents
CNTL	Control ID (Integer > 0)
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: `CHLTWC` Analysis control for rivet hole cracks

Description: Defines the control parameters for the analysis of cracks emanating from a rivet hole

Format and Example:

CHLTWC	CNTL	CASEID	PRINT						

CHLTWC	4	2	NO						

Field	Contents
CNTL	Control ID
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: CSF Analysis control for a surface flaw

Description: Defines the control parameters for the analysis of a surface flaw

Format and Example:

CSF	CNTL	CASEID	PRINT						

CSF	2	5	NO						

Field	Contents
CNTL	Control ID
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: `CHLSF` Analysis control for corner cracks emanating from a rivet hole

Description: Defines the control parameters for the analysis of corner cracks emanating from a rivet hole

Format and Example:

CHLSF	CNTL	CASEID	PRINT						

CHLSF	1	5	YES						

Field	Contents
CNTL	Control ID
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: `CCVC` Analysis control for a curved crack

Description: Defines the control parameters for the analysis of a curved crack

Format and Example:

CCVC	CNTL	CASEID	PRINT						

CCVC	2	5	NO						

Field	Contents
CNTL	Control ID
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: `CHLCVC` Analysis control for curved cracks emanating from a rivet hole

Description: Defines the control parameters for the analysis of curved cracks emanating from a rivet hole

Format and Example:

CHLCVC	CNTL	CASEID	PRINT						

CHLCVC	2	5	NO						

Field	Contents
CNTL	Control ID
CASEID	Astros Case ID (Integer > 0)
PRINT	Flag for result printing. (String, YES or NO)

Remarks:

1. None

Input Data Entry: CDSD Definition of control data of the discrete source damage problem

Description: This data entry describes the control data required for the discrete source damage problem. It specifies the following information for the discrete source damage problem: the fracture properties; the load case; and the variation of the half crack length. Single or multiple steps of the intermediate-local analyses with different crack lengths can be performed to calculate the beta factor. The range of steps is specified also. For multiple step intermediate-local analyses, a stress intensity factor is calculated for a crack that varies in length for each step. The beta factor is calculated from the stress intensity factor result for each step.

Format and Example:

CDSD	CNTL	FRACMT	CASEID	MINCRK	MAXCRK	NSTEP			

CDSD	1	2	5	6.0	9.0	4			

Field	Contents
CNTL	This field represents the data entry ID of this data entry. (Integer > 0)
FRACMT	Fracture property ID of the skin sheet of the panel. (Integer > 0)
CASEID	Loading case ID. (Integer > 0)
MINCRK	Minimum half crack length. (MAXCRK $\geq$ Real > 0.0)
MAXCRK	Maximum half crack length. (Real $\geq$ MINCRK)
NSTEP	Number of step between minimum and maximum half crack length. (Integer ≥ 0) (Default $= 0$)

Remarks:

1. FRACMT: This field represents the fracture property ID of the panel's skin. The fracture properties are then used for the fracture mechanics calculation of the local model.

2. MINCRK: This field represents the minimum half crack length of the discrete source damage problem.

   To analyze with the user defined settings, enter a value greater than zero. This value will be used as the minimum half crack length.

3. MAXCRK: This field represents the maximum half crack length of the discrete source damage problem.

   To analyze with the user defined settings, enter a value greater than zero. This value will be used as the maximum half crack length.

4. `NSTEP`: This field represents the number of steps of the discrete source damage problem.

   To analyze with the user defined settings, enter a value greater than zero. This value will define the number of steps required for the analysis.

   To analyze with the default settings, leave the value as zero. The program will then define the number of steps required for the analysis. If the value of MAXCRK equals MINCRK, then a one step analysis is set. If they are not equal, a two step analysis is set.

Input Data Entry: CBKDEL Definition of control data of the buckling and delamination problem

Description: This data entry describes control data required for the buckling and delamination problem. It specifies the following information for the buckling and delamination problem: the load case.

Format and Example:

CBKDEL	CNTL	CASEID							

CBKDEL	1	5							

Field	Contents
CNTL	ID of this CBKDEL data entry. (Integer > 0)
CASEID	Loading case ID. (Integer > 0)

Remarks:

1. None

Input Data Entry: `SIF` Beta factors for SIF

Description: Defines the beta factors for the stress intensity factors at one crack tip or a point on the crack front

Format and Example:

SIF	DMG	ID				BETA1	BETA2	BETA3	

SIF	2	1				1.01	1.13		

Field	Contents
DMG	Crack ID
ID	Tip/Point ID for the specific crack
BETAn	BETA1, BETA2, and BETA3 are beta factors for mode I, II and III. (Default = 0.0

Remarks:

1. Tip/Point ID for a given type of crack (for example, DTWC) are specified in the corresponding input card for that crack.
2. The definition of the beta factors are defined in the corresponding input cards for the cracks.

Input Data Entry: `FRACMT` Fracture material properties

Description: Defines the fracture material properites

Format and Example:

FRACMT	ID	KIC	KTH	COEF	EXPM	EXPN	EXPP	EXPQ	
FRACMT	1	90.0	20.0	3.0E-9	3.0				

Field	Contents
ID	Material property ID (FRACMT) (Integer > 0)
KIC	Critical Stress Intensity Factor K_{Ic} (Real > 0.0)
KTH	Stress Intensity Factor Threshold K_{th} (Real ≤ 0.0, Default $= 0.0$)
COEF	Coefficient c (Real ≥ 0.0, Default $= 0.0$)
EXPM	m (Real ≥ 0.0, Default $= 0.0$)
EXPN	n (Real ≥ 0.0, Default $= 0.0$)
EXPP	p (Real ≥ 0.0, Default $= 0.0$)
EXPQ	q (Real ≥ 0.0, Default $= 0.0$)

Remarks:

1. c, m, n, p and q are the coefficients in the following generic fatigue crack growth rate equation.
$$\frac{da}{dn} = \frac{c(\Delta K)^m(1-R)^p(\Delta K - K_{th})^q}{[(1-R)K_{Ic} - \Delta K]^n}$$
2. This generic fatigue crack growth rate equation becomes Paris equation when $n = p = q = 0$.
3. This generic fatigue crack growth rate equation becomes Forman equation when $n = 1$ and $p = q = 0$.